Assembly Motion Planning with Automatic Control-Parameters Adjustment Function

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論文内容要約

Industrial robot manipulators are used in factories to replace or assist human work-force. One of the key areas in manufacturing is the assembly of components. The assembly of components task comprises of two steps, first aligning the components for preparation of the assembly and the assembly of the components. The components being assembled are manipulated from initial state to the assembled state and require a trajectory for the assembly. During the alignment of the components for the preparation of the assembly the components should follow the desired path. But as the assembly progresses the components come in contact and compliance is required between the components.

Much research has been done for path planning, obstacle avoidance, peg-in-a-hole system, and control system development for assembly task in configuration space. A Configuration space of any object is the space of all the configurations of the object with respect to a reference frame. For the component assembly system, the assembled state is taken as the reference point and C-free is set of all the configurations where there is no collision between the components and C-obstacles are set of configurations for which there is a collision between the components.

Objective of this research is to generate a path for the assembly of components, selection of the velocity for assembly and finally automatic selection of control strategy. This research proposes a unified method for an assembly motion planning and automatic control parameters adjustment system for the assembly of components, by introducing a new concept of relative mobility potential in C-Space. Relative mobility potential is representation of permissible relative motion of the components at a given relative pose. Relative mobility potential calculated for the assembly of components in C-space is first used to plan the path for the assembly of components, next to select the velocity for assembly task and finally is used to select the control scheme for the component assembly task.

Exhaustive search (Brute force search) is used to calculate C-space and generate the relative mobility potential for the assembly task. To increase the efficiency of the system, the search area is bounded in the vicinity of the assembled state referred as analysis space. First configuration space is calculated for the assembly system, by keeping one component as static, which is the reference frame for the calculation of configuration space, C-free and C-Obstacles. C-free is a subset of all configurations in C-space for which there is no collision between the components. C-obstacles are subsets of the configuration in C-space for which there is a collision between the components.

Next relative permissible mobility between the components for all configurations is calculated. For a given relative pose the permissible motion between the components, is represented as a potential such that higher the relative mobility between the components, lower potential is assigned, thus creating a negative potential gradient from the assembled state to the disassembled state.

Relative permissible motion is calculated for both translational and rotational motion. Relative permissible motion for a given relative pose of components is determined as the ratio of permissible motion between the components without collision along a axis to maximum motion possible in that dimension. Translational and rotational mobility are calculated for both translation and rotational motion along x, y, z axis. Relative mobility potential is an artificial potential, created such that the relative mobility potential is low for high permissible motion and a high relative mobility potential is assigned for a small permissible motion.

In the disassembled state, the permissible relative mobility between two components is large, thus the relative mobility potential is low. As the components are aligned for the assembly, the permissible relative motion reduces and, the relative mobility potential increases. To generate a path for assembly relative mobility potential is coupled with distance potential.

Distance potential is calculated for all the configurations in analysis space. Distance is calculated for each pose in analysis space, with respect to the assembled state. Distance potential of a given configuration is ration of distance of the configuration from assembled state to maximum distance from assembled state in the analysis space. The distance potential generated by this method is has a repelling potential from the assembled state. Distance potential is superimposed with relative mobility potential to calculate the total potential used for path generation for assembly of components.

Total mobility potential has a negative potential gradient from assembled state to disassembled state. Path for the assembly of components is planned in reverse direction, i.e. from assembled state to disassembled state. The relative mobility potential is higher in the assembled state, compared to the disassembled state. The distance potential is also a repelling from the assembled state to the disassembled state. Hence the total potential obtained by superimposing is also high in assembled and reduces in disassembled state. Path is generated by following negative potential gradient, from assembled state to disassembled state.

The path for assembly generated by potential variation, gives via points (pose in C-space) which need to be traced for the assembly. The objective is to select the velocity so that the velocity is high in the disassembled state and velocity reduces as the assembly progresses. The velocity is selected by selecting the time to move component from one via point to next via point in a path, which is calculated using relative mobility potential. In the disassembled state, the relative mobility potential is low and the time required to traverse two consecutive path points is minimum time required to meet the speed limit of the robot manipulator.

As assembly progresses the relative mobility potential rises and the time required to move between two consecutive path point increases thus reducing the velocity of the system. Thus the time required to move component from one via point to next via point slowly increases, and velocity slowly decreases as the assembly progresses. Trajectory is generated using cubic hermit spline. Cubic spline function ensures that second order derivatives are continuous.

The velocity at disassembled state is calculated by calculating the time required to move from starting point to first via point, when traversing with maximum velocity in each dimension. The maximum time required for motion in translation or rotation in along any axis is taken as base time and added with potential of that via point to determine the desired time for motion. The process is repeated for all via points for assembly and then trajectory is generated using cubic hermit spline.

During the assembly process components are aligned for the assembly and then finally assembled. Alignment of the components require trajectory control, while during assembly components come in contact, and hence compliant motion control is required. In this research impedance control scheme is used to implement compliant motion control for assembly of components.

The impedance control is a type of compliant motion control schemes used for tasks having physical interactions between the manipulated object and its environment. When external forces/moments are applied to the manipulated object, the impedance control scheme generates deviation of the trajectory of the manipulated object from its reference trajectory dynamically. The external force/moment applied to the manipulated object is usually measured by a force/torque sensor attached to the wrist of the robot manipulator.

The relative mobility potential is used to tune the impedance parameters, to automatically achieve the desired control. The impedance parameters are inversely proportional to the potential. In disassembled state the potential is low, thus the impedance parameters are large, and the system works in trajectory control. As the assembly progresses, the potential increases, and the impedance parameter reduces, thus gradually changing the system to compliant motion control. The concept is experimentally verified for a peg-in-a-hole system.

To automate the process of assembly, various technical problems need to be addressed as mentioned above. A path needs to be chosen to align the components for assembly. When components are aligned for the preparation of the assembly, their position needs to be controlled; hence a trajectory controller is used. When the assembly process starts, components come in contact with each other, hence compliant motion control is required. Relative mobility potential based system can simultaneously handle path generation, select appropriate velocity along the path and automatically tune the control parameters for the assembly of components to achieve an automated assembly process in the manufacturing system.

Hence by introducing an artificial potential which represent the permissible motion of the components for a relative configuration, a unified method for path generation, trajectory generation, and control scheme selection is proposed and experimentally verified for a simple rectangular peg-in-a-hole system. However exhaustive search method is used to calculate configuration space and relative mobility potential, which is done off-line. The system has to be made faster so as to generate the relative mobility potential, path, and trajectory and vary the impedance parameter on-line. In addition, the system selects the initial impedance parameters based on the application of task. A further study is required for initial selection of impedance parameters. These issues will be studied in future work.